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INVESTIGATION OF FRICTION BEHAVIOR OF AA2090 AL-LI ALLOY IN CYLINDRICAL DEEP DRAWING SHEET METAL USING FINITE ELEMENT

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ABSTRACT

The good quality of the final shape during deep drawing process is highly required; moreover, the control of physical and geometrical parameters is mandatory to reduce defects. Friction is a significant geometrical parameter that influences the deformed shapes. This paper aims to analyze the behavior of friction in AA2090 aluminum lithium alloy for three different regions of a cylindrical deep drawing. Therefore, the distribution of the blank thickness has been studied; finite element analyses were used by Abaqus software to model a three-dimensional cylindrical deep drawing model. A mixture of finite element model and parametric optimization of Taguchi method was carried out. The results obtained from finite element analysis were utilized as inputs of parametric optimization to identify the most suitable grouping of the Coulomb friction in the three different areas.

KEYWORDS: Al-Li, Deep Drawing, Finite Element, Friction & Taguchi Method

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Original Article

1. INTRODUCTION

In order to enhance to proximately 80% of the aircraft weight, aluminum alloy was used over the past century. However, other materials such as highly competitive Al titanium alloys and composite materials were used [1], therefore, aluminum manufacturers worked on a novel kind of Al alloy, which is Al–Li alloys [2].

Li is the third component in periodic table, which made it the lightest metallic element, when 1% Li alloyed to Al, 3% decreases in density, and approximately raise 6% in elastic modulus [3] [4]. Also, the adding of 2% Li reduces 10% of density, and increases 25% to 35% of modulus of elasticity [5]. Besides, a reduction between10% and 20% of the structural quality and an augmentation of the rigidity between 15% to 20% can be achieved [6].

AA2090 is an aluminum-lithium alloy, which provides improved exfoliation corrosion and SCC resistance, along with higher strength levels for a given temper and excellent weldability. The characteristic of AA2090 was examined by Gaoshan et al. [7], with the intention of enhancing its formability.

The ability of the material to be deformed with no defects is influenced by several parameters [8]. In order to avoid imperfect results, a precise description of these parameters is highly required. Several failure types were investigated using FEM such as wrinkling [9], thinning [10], spring back [11] and earring [12].

During deep drawing process, the deformed blank is influenced by the type of the contact with the tools; therefore studies were focused on its impact on the drawn part. Hjijaj et al. [13] used the friction model based on the Coulomb law, in order to generalize the friction condition of non-associated sliding rule Z. Mróz et al. [14] studied the theoretical methodology of sliding bases as well the friction limit surfaces. Jayahari et al [15] evaluate the coefficient of friction between the deformed shape and tools using both finite element analysis and experimental set up. Brown et al. [16] studied the effect of the type of lubrication and location on drawing formability. Zhrgang Wang [17] conducted a finite element simulation and examined the friction between the die and the lubricant coated sheet steel by changing the coefficient of friction between the mold and the lubrication layer.

The goal of this research is obtaining a better understanding of the effect of friction during deep drawing process. Therefore, studied the thickness distribution of the finite element drawn blank using ABAQUS 6.14 software. The results obtained from the simulation were used in Taguchi statistical approach, to investigate the proper combination between the three different regions using Taguchi method.

2. FINITE ELEMENT OF DEEP DRAWING

2.1 Geometry of the Cylindrical Drawn Cup

Figure 1, illustrates different friction areas that can occur during a deep drawing process. The blank was deformed using the punch force Fp, while it was compressed by the blank holder Force F_H.

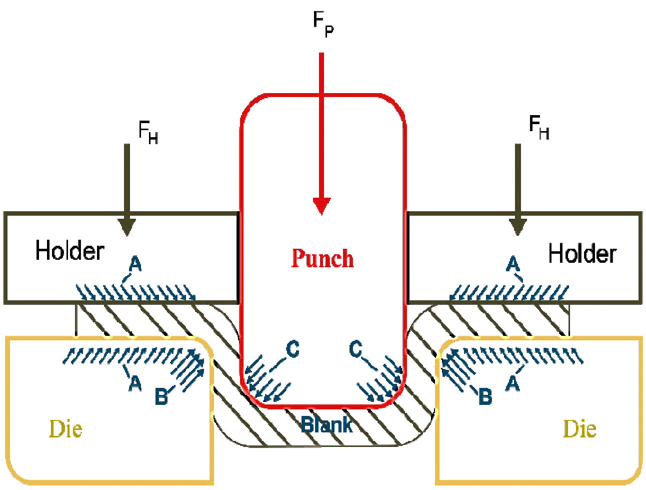


Figure 1: The three Friction Regions during Deep Drawing:
A) Between the Flange of the Blank and the (Die and Blank Holder)
B) Between the blank and the Die Corner Radius
C) Between the Blank and the Punch Nose Radius

The force application area is in the bottom of the blank, as it is illustrated in figure 2. After the application of the punch force in this region, it is transferred lengthwise, the wall into the flange. The force transformation in one deep drawing process requires a specific value of friction coefficient in each are. In order to obtain a good quality of the final drawn cup, a deep study of the friction is required.

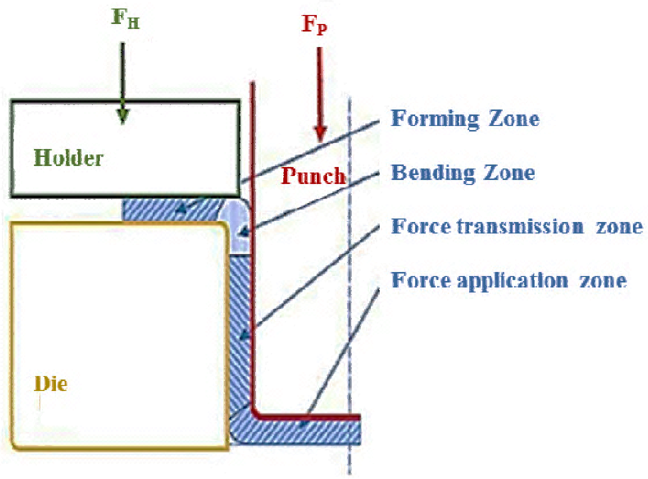


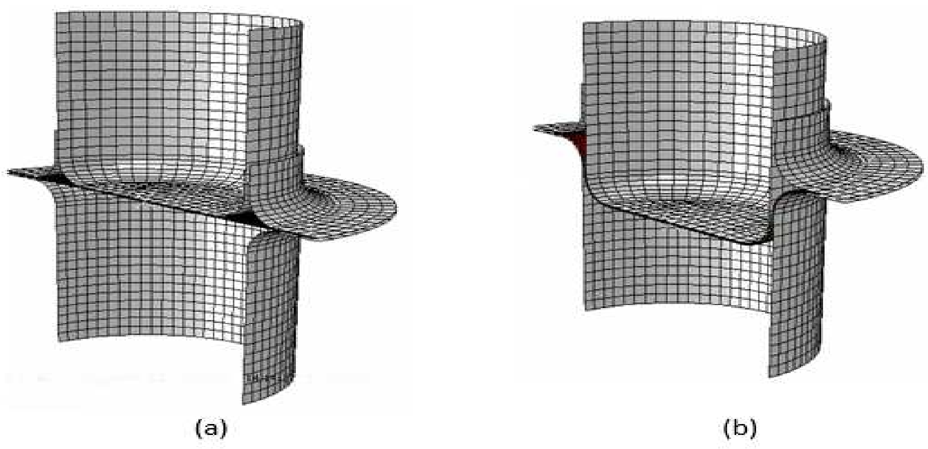
Figure 2: The Tansformation of the Punch Force during the Deep Drawing Process.

2.2 The Validation of the Cylindrical Drawn Model

In our finite element model, the blank was modeled as deformable body while tools were as rigid bodies. The meshing of these tools in the present three-dimensional cylindrical drawing model was with (R3D4) surface elements, and using reduced integration shell element (S4R) for the sheet blank [18].

Table 1 presents the dimensions employed in our simulation, while table 2 illustrate the mechanical properties of AA2090 Aluminum Lithium alloy [19].

As shown in figure 3, corresponding symmetry boundary condition was modeled using ABAQUS software, also the mass scaling was utilized with the aim of decreasing the CPU time as well the computer memory.



(a) Before Deformation, (b) During Deformation
Figure 3: 3D Finite Element Cylindrical Deep Drawing Model.

Table 1: The Dimensions of the Numerical Model

Punch diameter (mm)	Punch nose radius (mm)	Die diameter (mm)	Die corner radius (mm)	Blank thickness (mm)	Blank diameter (mm)
97.46	12.7	101.48	12.7	1.6	158.76

Table 2: Mechanical Properties of AA2090 Al-Li Alloy

ρ (Kg/dm3)	E (GPa)	υ	Hardening law
2.89	78.6	0.3	$\sigma=646(0,025+\varepsilon)^{0,227}$

The results obtained from the table.3 shows the present study accord with the smallest thickness at the nearest node to the matching point, found by the research of Colgan et al [20]. As shown in figure 4, eight thickness values were extracted from the output data. In addition, current results are so close to those obtained by Colgan et.al, with variances less than 0.4% on average for numerical values and less than 2.2% on average for experimental results.

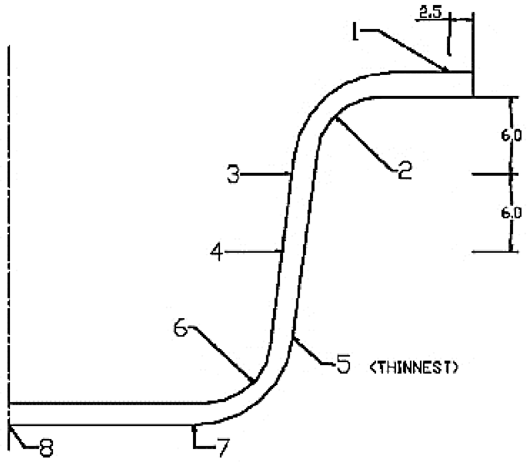


Figure 4: The Measured Thickness Locations.

Table 3: Comparison of Thickness Distribution of the Final Drawn Part Between the Present Model and Published Results

	1	2	3	4	5	6	7	8	Average
Colgan et al's Experimental results	1,132	1,032	0,888	0,83	0,823	0,871	0,966	0,979	0,94013
Colgan et al's FEA results	1,11	1,08	1,01	0,955	0,799	0,844	0,942	0,958	0,96225
Present FEA	1,10	1,05	1,01	0,91	0,881	0,899	0,942	0,940	0,966261

3. RESULTS & DISCUSSIONS

The study of the variation of thickness is the most used parameter for the analysis of the quality of sheet drawn cup. Therefore, the base of the current paper is to study the effect of friction on thickness and thinning.

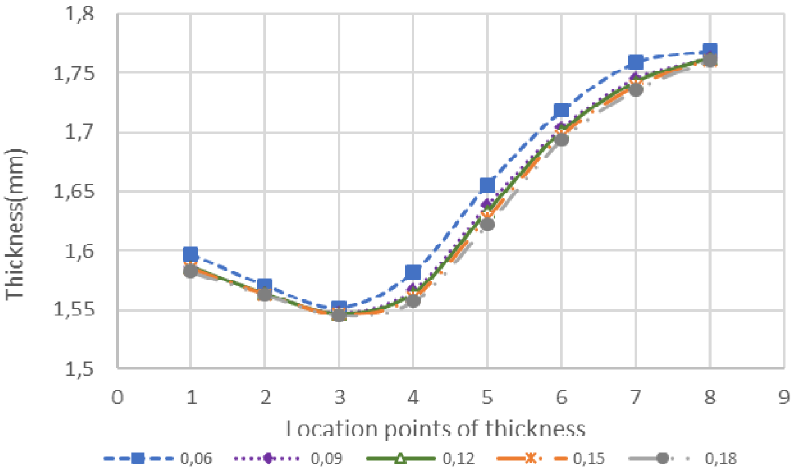


Figure 5: The Impact of µd on Blank Thickness Distribution.

The required energy for the deformation of the blank, the punch and the blank holder forces, is affected by the friction coefficient. A control of contact between the blank and the three different tools (holder, punch and die) is absolutely necessary [21].

Table 4: Blank Thickness Variation with µd

Points of Measured Thickness	µd				
	0,06	0,09	0,12	0,15	0,18
1	1,59713	1,58631	1,58599	1,58478	1,58241
2	1,57073	1,56375	1,56341	1,56314	1,5629
3	1,55184	1,54742	1,54693	1,54632	1,5459
4	1,58149	1,56652	1,56376	1,56035	1,55729
5	1,65569	1,63825	1,63303	1,62765	1,62203
6	1,71832	1,70358	1,70021	1,69682	1,69337
7	1,75894	1,74546	1,74209	1,73878	1,73576
8	1,76913	1,76307	1,76212	1,76154	1,76103
	1,65040875	1,639295	1,637193	1,6349225	1,63258625

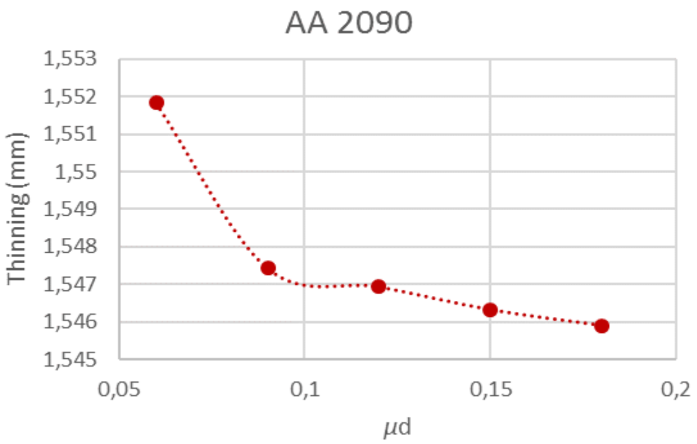


Figure 6: Thinning's Variation with µd.

The purpose of lubrication between the blank and the die is to reach a minimum contact. With increasing the coefficient of friction µd, the values of thickness are decreased as illustrated in figure 5 and table 4, while the thinning is

increased as shown in figure 6. The results obtained prove that the suitable lubricant in this region must be a fluid lubricant.

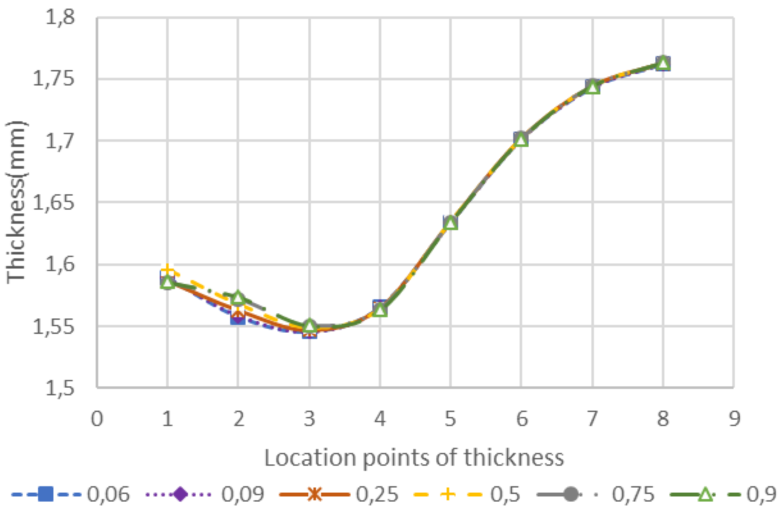


Figure 7: The Impact of µp on Blank Thickness Distribution.

Table 5: Blank Thickness variation with µp

Location of Blank Thickness	**µp**						
	0.06	**0.09**	**0.25**	**0,5**	**0.75**	**0,9**	**1**
1	1,58913	1,58899	1,58633	1,59552	1,58512	1,5859	1,5884
2	1,55765	1,55873	1,5625	1,5676	1,57181	1,5738	1,5753
3	1,54568	1,54579	1,54656	1,54873	1,55041	1,5508	1,5511
4	1,56539	1,56509	1,56456	1,56393	1,5639	1,5633	1,5636
5	1,63401	1,63415	1,63428	1,63448	1,63437	1,6342	1,6342
6	1,7015	1,70145	1,70147	1,70159	1,70169	1,7016	1,7016
7	1,74314	1,74323	1,74358	1,74404	1,74423	1,7441	1,7442
8	1,76208	1,76222	1,76231	1,76274	1,76296	1,7629	1,763
average	1,6373225	1,63745625	1,637699	1,63982875	1,63931125	1,6396	1,6402

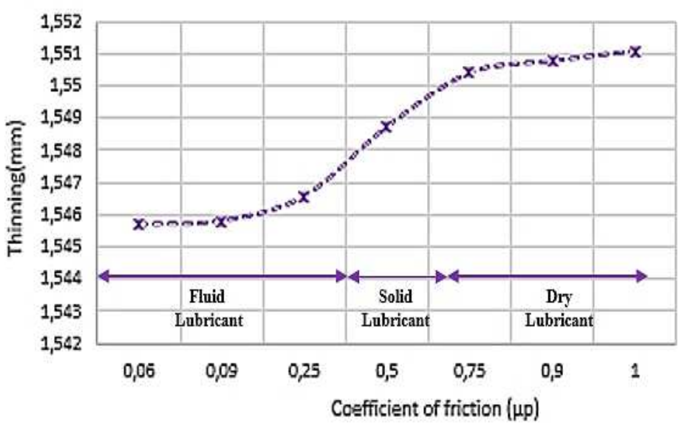


Figure 8: Thinning's variation with µp.

The thickness distribution rose with the augmentation of coefficient of friction µp, as it is described in figure.7 and table 5. Furthermore, thinning continuously increasing till it becomes stable for the solid and dry lubricant and

increasing slowly for fluid lubricant, while it is very low when the fluid lubricant is between 0.06 and 0.2, as shown in figure 7

A higher coefficient of friction is demanded for the transformation of the punch force on the outside region. In this case, both the top blank surface and the bottom of the punch must not be lubricated. The first rule for lubrication is clarified in this region.

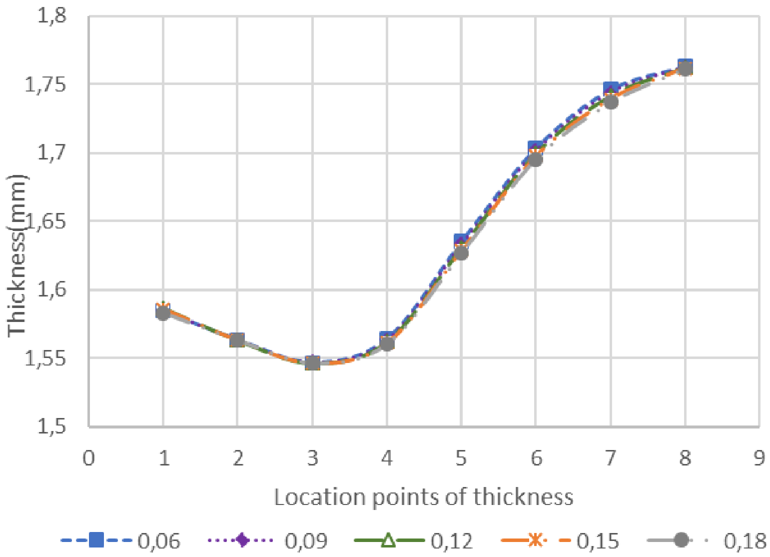


Figure 9: The Impact of μh on Blank Thickness Distribution.

Figure 9 and Table 6 indicate the variation in thickness with μh. In addition, figure 10 illustrates the influence of μh on thinning.

Table 6: The variation of Blank Thickness with μh

Location of blank thickness	μh				
	0.06	0.09	0.12	0.15	0.18
1	1,58451	1,58481	1,58683	1,58601	1,58316
2	1,56354	1,5634	1,56331	1,5632	1,56307
3	1,54691	1,54699	1,54665	1,54643	1,54641
4	1,56413	1,56317	1,56207	1,56098	1,5602
5	1,63501	1,6329	1,63069	1,62871	1,62664
6	1,70325	1,70131	1,69928	1,69741	1,69542
7	1,7461	1,74382	1,74149	1,73909	1,73666
8	1,76312	1,76265	1,76197	1,76168	1,76126
Average	1,638321	1,637381	1,63653625	1,63543875	1,6341025

The thinning decreased when ud is between 0.12 and 0.18, which corresponds to the fluid lubricant, as shown in figure 10.

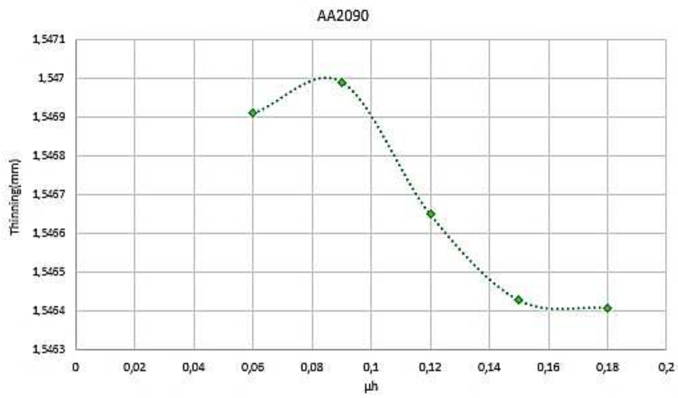


Figure 10: The variation of Thinning with μh.

In order to minimize the contact in the punch side, lubrication must be a lubricant ring on the blank holder. Yet, if the lubrication film used is extreme and the high viscosity oils and the stretching pastes are accurate, the appearance of wrinkling is high because of the decrease of the friction μh in this region.

A combination of the parametric optimization of the statistical Taguchi approach with finite element simulation was investigated to examine the evaluation of the friction between the deformed blank and the three different tools. The orthogonal array of Taguchi, adjoin the design, in such a technique the different factors are similarly weighted. Because of this, the evaluation of each one could be considered separately, which means that this evaluation is not influenced from one factor to another.

Table 7: Process Parameters and their Levels

Process parameter	Levels		
	1	2	3
Coefficient of friction between blank and die μd	0.14	0.16	0.18
Coefficient of friction between blank and holder μh	0.14	0.16	0.18
Coefficient of friction between blank and punch μp	0.1	0.15	0.20

The values of the selected control parameters are based on the results of the previous finite element model reported in the previous session. For each factor, three levels were selected as mentioned in table 7. The coefficient of friction varies, the orthogonal network L9 has already been used to perform the new nine simulations, as given in table.8.

Table 8: Orthogonal Array (L9)of Taguchi Method

Treat No	Coefficient of friction between blank and die μd	Coefficient of friction between blank and holder μh	Coefficient of friction between blank and punch μp
1	0.14	0.14	0.1
2	0.14	0.16	0.15
3	0.14	0.18	0.2
4	0.16	0.14	0.15
5	0.16	0.16	0.2
6	0.16	0.18	0.1
7	0.18	0.14	0.2
8	0.18	0.16	0.1
9	0.18	0.18	0.15

The concept of signal-to-noise ratio (S/N ratio) in Taguchi method aims to improve quality by reducing contrast and developing measurements [22].

The orthogonal test L9 (33) illustrated in table 8, was employed in this research based on the number of levels and the test factor as well (Table 7). S / N ratio was found out for each specific element analysis and the thinning results obtained from each model, as described in table 9.

After the nine tests, the Taguchi approach was employed to obtain the optimal level of friction for each region during the deep drawing operation, in order to improve the thinning of the final deformed shape. The percentage of the contribution of friction on each region is given in table 10. The optimum results of the areas are given beyond to improve the thinning in the final drawn cup.

Table 9: Signal to Noise Ratios

Level	µd	µh	µp
1	2.877	2.904	2.455
2	2.887	2.883	2.812
3	2.636	2.613	3.133
Delta	0.251	0.291	0.678
Rang	3	2	1

Table 10: Optimum Condition and the Contribution of Each Factor

Process Parameters	Level	Contribution %
µd	2	27
µh	1	33
µp	3	40
Thinning (mm)	1.4445	

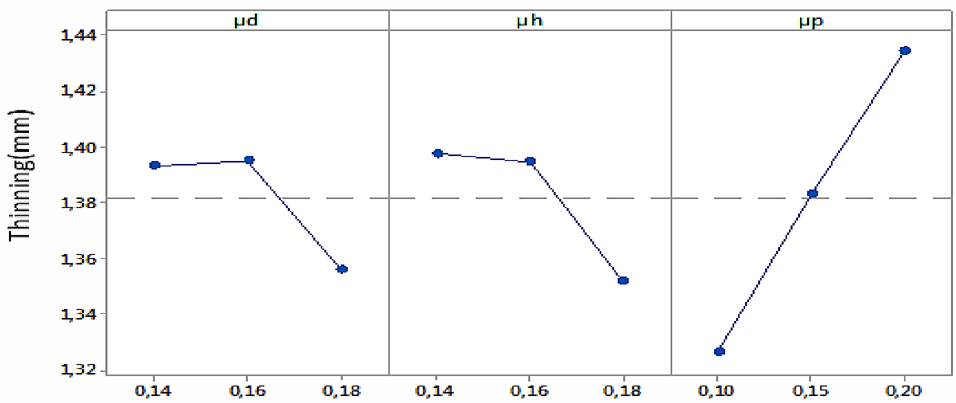


Figure 11: Variation of Thinning with the Variation of Control Parameters.

The final results obtained in figure.11 show that the optimum coefficients to enhance the quality of the deformed shape are the level 2 for µh coefficient, level 1 for µp coefficient and level 3 for the µp coefficient. In order to ensure the optimum condition found, an extra run using ABAQUS was done and the value of thinning obtained was 1.4445 mm, which is the higher value compared to the pervious results obtaining in table 4, which confirmed the validation of the parametric optimization done by Taguchi method.

4. CONCLUSIONS

Finite element constitutes a powerful tool to attain a realistic solution with a reduction of expense, time and error efforts. In our present paper, ABAQUS software was used for the prediction of contact impact in AA2090 Aluminum lithium alloy sheet. Basing on finite element outcomes, the appropriate range of contact surfaces between the blank and the punch is 0.06<µp <0.2, while 0.12 <µd <0.18 and 0.12 <µh <018. These obtained results were used in parametric optimization method of Taguchi, and it was concluded that the optimum combination is 0.16; 0.14 and 0.20 concerning µd, µh and µp, respectively. µp is the most contributing parameter with a percentage of 44%, followed by µh with a percentage of 33%, and the less contributing is µd with a percentage of 27%.

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His main research interests are in the area of fatigue of mechanical structure such as welded and riveted joints, (either by numerical simulation or experimental investigation), he edited more than 10 books in field of Automation, Robotic, Non-Destructive Tests, and mechanical drawing, and published more than 15 papers in refereed journals and more than 45 papers in national and international conferences, he also supervised 20 Master and PhD projects and examined more than 20 Master and PhD projects. Website: http://ghanameh.tarkiah.com/.

Pr Mohamed MADA is a Professor of Higher Education Grade C. He is a former Head of Process Engineering Department and an EX-Deputy Head of Process Engineering department. He is an Elected member of the governing board. Elected member of the scientific committee, Co- Head of the Industrial Rheology and Energetics Laboratory in the Process Engineering Department at the Mohammedia School of Engineers (Mohamed V University) and a director of the research group on the use of solar energy J.E.R N ° 6025 funded by the Aupelf-Uref (1998-2002). Coordinator of the Mediterranean network of engineering schools in Morocco (RMEI). (2000-2005).Dr Mohamed MADA is working now in several projects which are: Project of desalination by solar energy of sea water by freezing, and by humidification dehumidification. Research and development project (2014-2018).

- Project of solar desalination of seawater by evaporation. Research and development project (IRESEN, UIR and EMI) 2015-2019
- Characterization and optimization of the formability and the heat treatment of Aluminum - Lithium alloys for the lightening of structures in aeronautics (Bombardier, UIR and EMI) 2016-2020

Dr. Elhachmi Essadiqi, is currently Dean of Aerospace Engineering school at the University International de Rabat, Morocco and adjunct professor at Mississippi State University. His main research interests are in the area of light weighting materials for automotive and aeronautics applications (e.g. Al – Li); microstructure and properties relationship in ferrous and non-ferrous alloys.

Dr. Essadiqi developed a twin roll casting process and design thermo-mechanical processes for new magnesium – RE alloys sheet, in collaboration with General Motors, Novelis, Mag NET (network of excellence of 5 Canadian Universities) and Helmholtz GeesthachtZentrum (old GKSS) in Germany. He is now working on seawater desalination using solar energy and recycling of solid materials such as steel and Mg alloys